

Framework to do

From 3 to 10 TeV

Federico Meloni (DESY),
with many thanks to all who, directly or indirectly, provided inputs

Muon Collider Physics and Detector workshop
FNAL, 16/12/2022



What's this talk about?

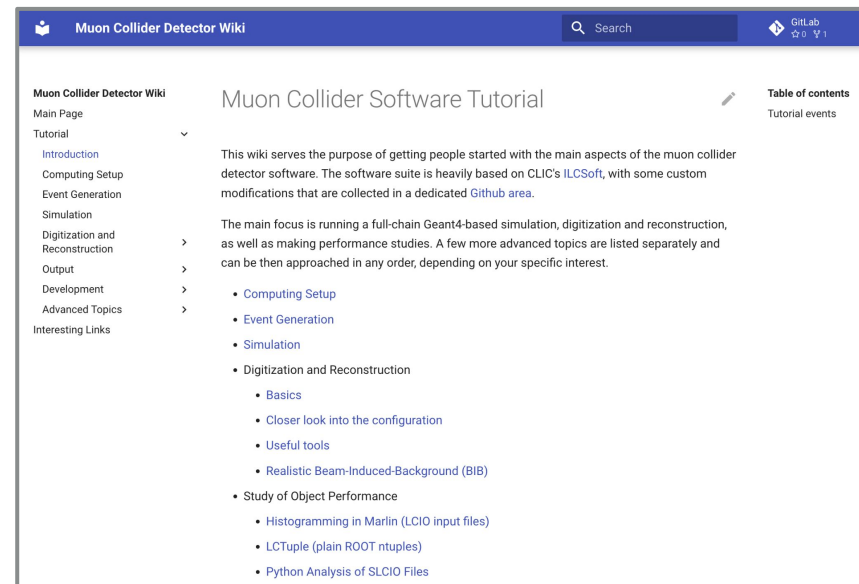
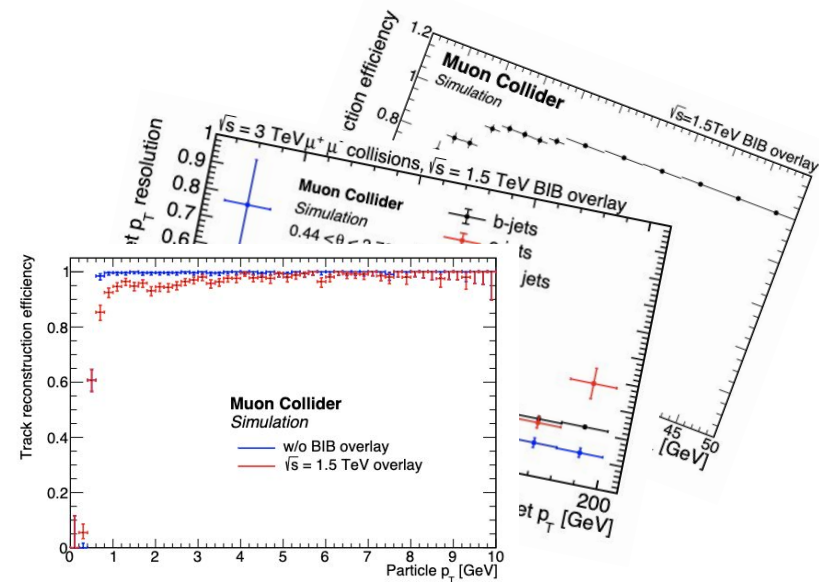
Our full simulation framework made giant leaps in the past few years

Snowmass21: shown \sim LHC-level performance for most physics objects

- We should not stop there

How can **you** help?

This talk includes a non-exhaustive list of ideas. Get in touch for more!



Recommended entry point
<https://mcdwiki.docs.cern.ch/tutorial/>

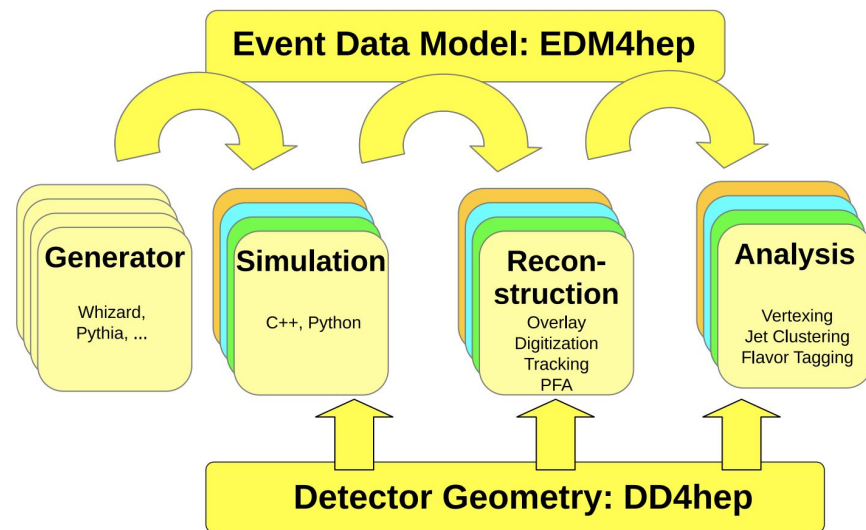
Core framework changes

Migrating to key4HEP

Maybe the “**single**” most important (software) **change** to do in the near term

- Migrate to modern software framework and interfaces
- Support for multi-threaded processing (will require writing thread-safe algorithms)
- Adopted by other future colliders, but still flexible (i.e. EDM changes)
- We can't afford to branch off

Work is already ongoing, but it's a significant effort and there are many tasks to be picked up.

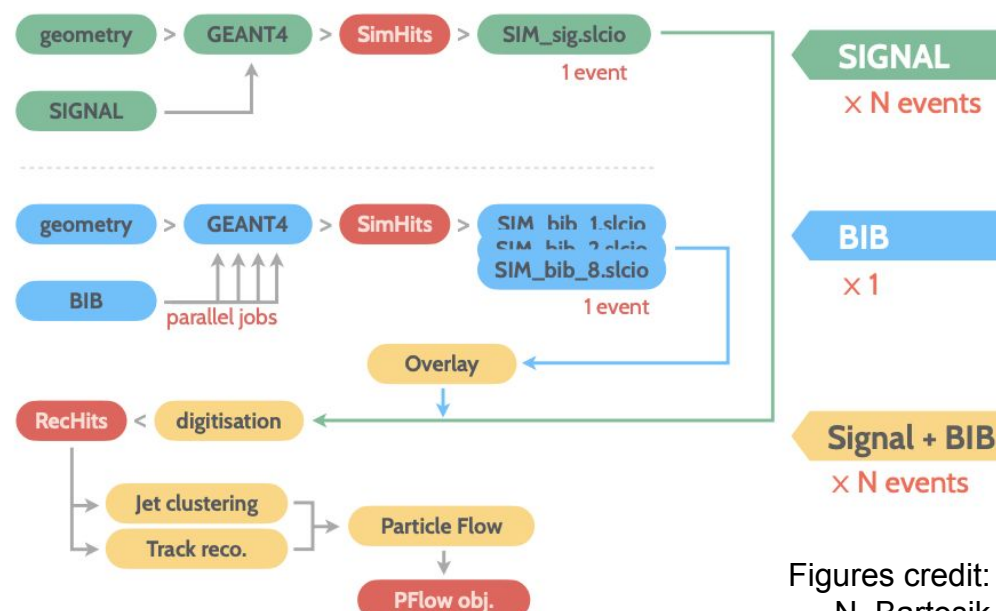


	Marlin	Gaudi
language	c++	c++
working unit	Processor	Algorithm
configuration language	XML	Python
set up function	init	initialize
working function	processEvent	execute
wrap up function	end	finalize
Transient data format	LCIO	anything
Executable	Marlin	k4run

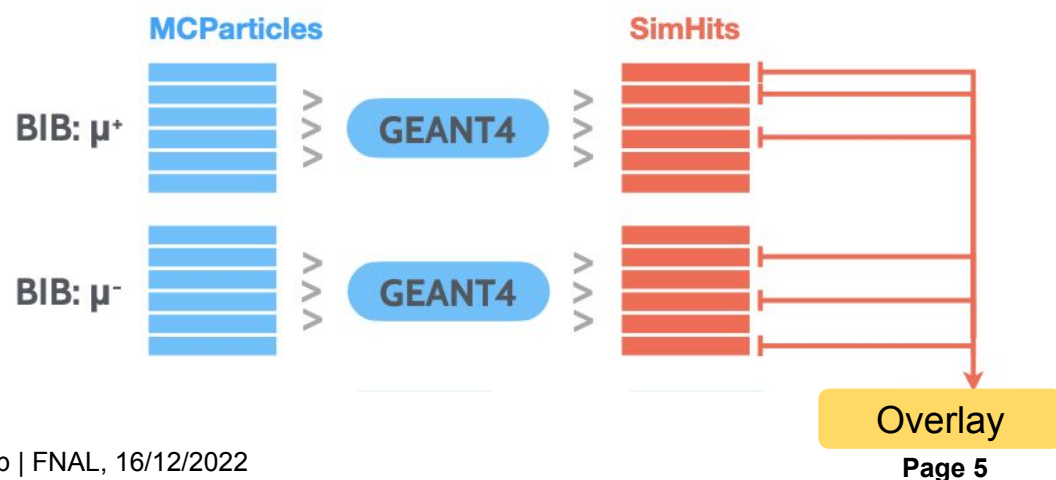
BIB generation and simulation

The production of BIB files from MARS15 for the overlay is currently limited to few super-experts

- FLUKA-based pipeline in development
- Standardize workflow and include necessary software in docker images
- Document or automate procedure to lower the barrier for entry
- Develop of random overlay of BIB-batches from FLUKA



Figures credit:
N. Bartosik



BIB overlay and beyond

Realistic digitisation of tracker modules available

- To save CPU time, design direct overlay of digitised hits

Similar opportunity for calorimeters - develop libraries of pre-digitised (i.e. time-integrated) BIB contributions

BIB overlays for fast simulation (Delphes)?

- Build libraries of high-level objects to overlay directly in the fast simulation
e.g., combinatorial BIB tracks, BIB jets ...

Muon detectors as trackers

For historical (?) reasons, muon detectors are implemented in the framework as calorimeters

This makes it hard to run tracking algorithms to reconstruct muons

Reconstruction has to go through PandoraPFA reducing flexibility/interpretability of results

```
////////////////////////////////////
EVENT: 4
RUN: -1
DETECTOR: MuColl_v1
COLLECTIONS: (see below)
////////////////////////////////////
```

COLLECTION NAME	COLLECTION TYPE	NUMBER OF ELEMENTS
ECalBarrelCollection	SimCalorimeterHit	1181
ECalEndcapCollection	SimCalorimeterHit	1
HCalBarrelCollection	SimCalorimeterHit	52
HCalEndcapCollection	SimCalorimeterHit	226
HCalRingCollection	SimCalorimeterHit	18
InnerTrackerBarrelCollection	SimTrackerHit	6
InnerTrackerEndcapCollection	SimTrackerHit	0
MCParticle	MCParticle	19
OuterTrackerBarrelCollection	SimTrackerHit	4
OuterTrackerEndcapCollection	SimTrackerHit	5
VertexBarrelCollection	SimTrackerHit	11
VertexEndcapCollection	SimTrackerHit	4
YokeBarrelCollection	SimCalorimeterHit	0
YokeEndcapCollection	SimCalorimeterHit	21

Tools and quality of life

Pandora PFA

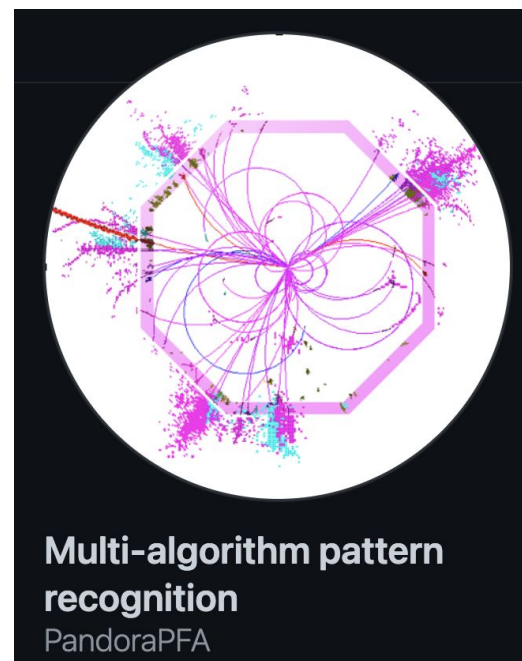
- At core of the reconstruction of most of our high-level objects
- Systematic lack of experts!

Columnar analysis

- FCC-analysis framework uses RDataFrame for event processing
- Processing LCTuples with coffea (Lindsey Gray offered help during the tutorial, thanks!)

Documentation

- Small contributions can make a difference



zenodo

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November 5, 2022 Software Open Access

CoffeaTeam/coffea: Release v0.7.20

Lindsey Gray; Nicholas Smith; Benjamin Tovar; Andrzej Novak; Jayjeet Chakraborty; Peter Fackeldey; Nikolai Hartmann; Gordon Watts; Douglas Thain; Giordon Stark; BenGalewsky; Jonas Rübenach; Benjamin Fischer; Devin Taylor; MoAly98; Dmitry Kondratyev; Paul Gessinger; Yi-Mu "Enoch" Chen; Joosep Pata; Anna Woodard; Andreas Albert; slehti; Zoe Surma; Alexx Perloff; Kevin Pedro; dnoonan08; Andrew Hennessee; Karol Krizka; kmohrman; Lukas

Basic tools and wrappers for enabling not-too-alien syntax when running columnar Collider HEP analysis.

[Preview](#) >

Files (12.0 MB)	
Name	Size
CoffeaTeam/coffea-v0.7.20.zip	12.0 MB

md5:05e048957e6a30757919dcea060d6caa ⓘ

[Preview](#) [Download](#)

Knowledge transfer from the LHC

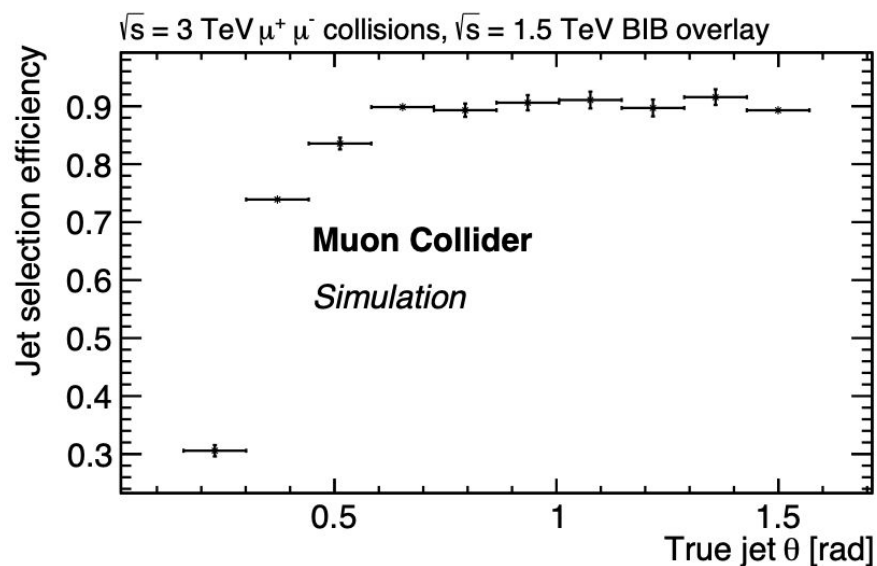
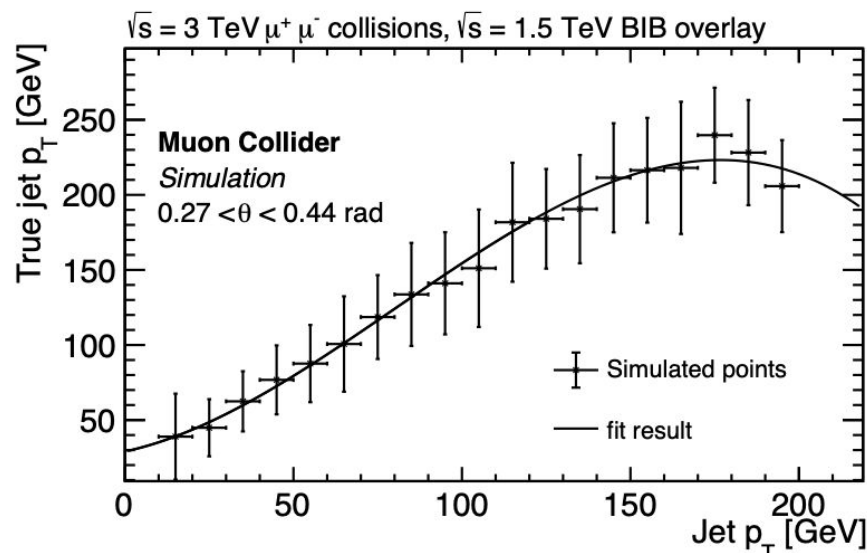
Jets

Obvious place where to transfer knowledge from LHC

- Pile-up (BIB) subtraction
- Jet energy calibration
- Reconstruction of boosted objects / substructure techniques

BIB rejection based on tracks introduces inefficiencies where tracking performance still suboptimal

- Develop more sophisticated criteria
- Study simple adjustments, e.g., setting an upper energy threshold to the BIB cleaning



Go beyond SV-based flavour tagging

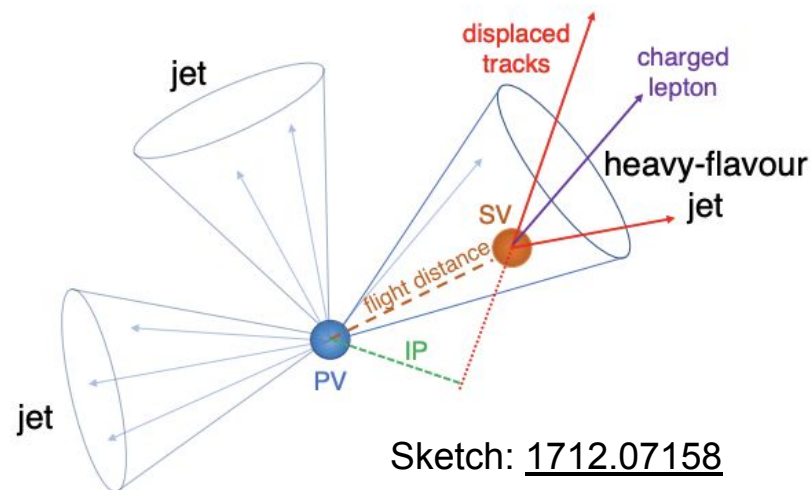
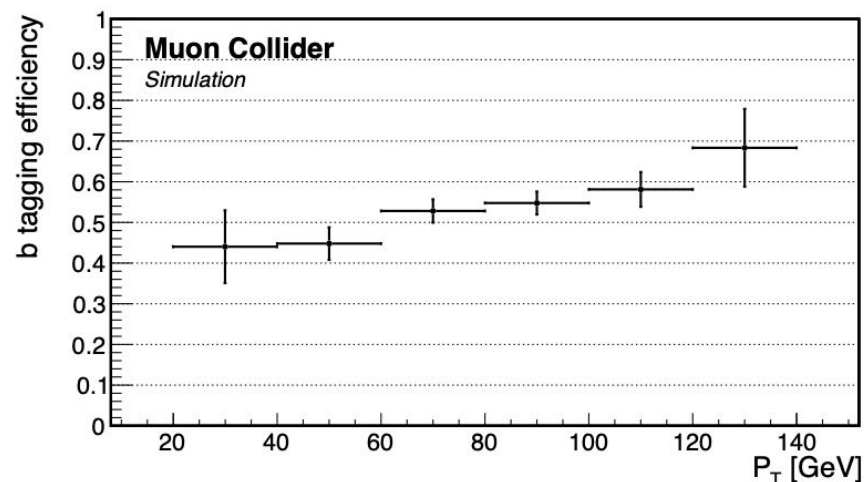
Currently relying on robust flavour tagging algorithm based on the presence of secondary vertices

Need to exploit all the information that is available

- Track impact parameter
- Charged leptons from meson decays

Move away from tracking inputs based on double-layer filtering

Develop your favourite machine learning approach



Slide intentionally left blank
(everything needs to be done!)

Defining standards

Some of you might be interested in simply evaluating the sensitivity of your favourite physics channel using the state-of-the-art simulation



- Started work on defining standard working points for tracks (see [N.Bruhweiler's talk](#))
- Need to do the same for all other reconstructed physics objects

Greatly lower the barrier of entry for performing physics studies with full simulation

Combining with track filter

	Fake tracks/event	Average efficiency (small sample)
Unfiltered	72,765	100%
Track filter only	2,887	96%
Both track and cluster filter (loose)	2,080	95%
Both track and cluster filter (tight)	1,703	95%

[N.Bruhweiler](#)

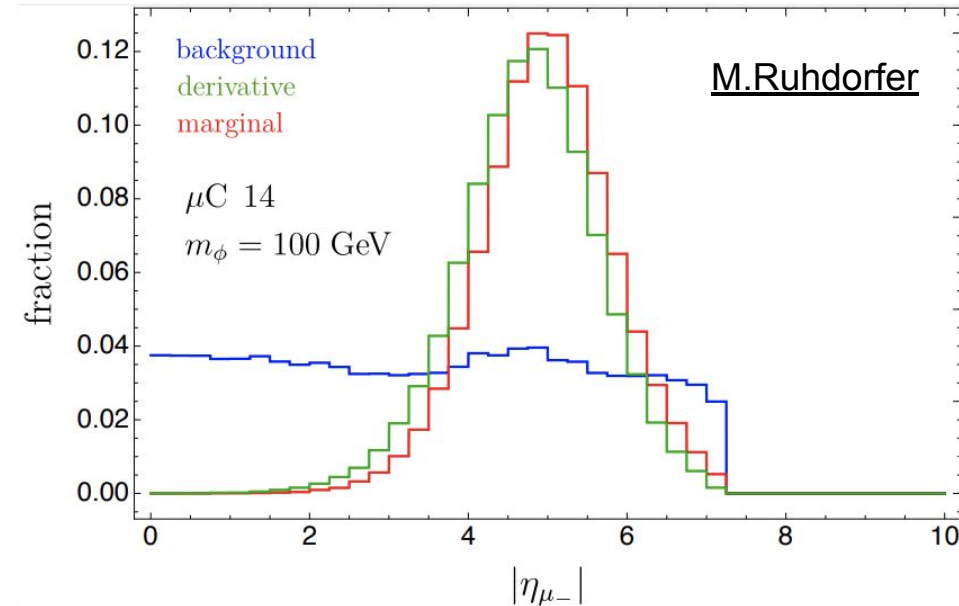
Forward detectors and physics

The forward region

Instrumenting the forward region (down to 0.1 degrees from the beam axis) would strongly boost the physics potential of a muon collider

- Need to design the detector (technology? strategy?)
- Investigate integration with accelerator (focusing magnets?)
- Insert detector in simulation
- Design dedicated reconstruction algorithms
- Evaluate impact on physics

Bonus interplay with luminosity measurements!



Removing forward tagging
mainly affects κ_Z :

- $1.2\% \rightarrow 5.1\%$
- $0.34\% \rightarrow 1.4\%$

M. Forslund

The ultra-forward region

Monte Carlo simulator	MARS15	MARS15	FLUKA	FLUKA	FLUKA
Beam energy [GeV]	62.5	750	750	1500	5000
μ decay length [m]	$3.9 \cdot 10^5$	$46.7 \cdot 10^5$	$46.7 \cdot 10^5$	$93.5 \cdot 10^5$	$311.7 \cdot 10^5$
μ decay/m/bunch	$51.3 \cdot 10^5$	$4.3 \cdot 10^5$	$4.3 \cdot 10^5$	$2.1 \cdot 10^5$	$0.64 \cdot 10^5$
Photons ($E_\gamma > 0.1$ MeV)	$170 \cdot 10^6$	$86 \cdot 10^6$	$51 \cdot 10^6$	$70 \cdot 10^6$	$107 \cdot 10^6$
Neutrons ($E_n > 1$ MeV)	$65 \cdot 10^6$	$76 \cdot 10^6$	$110 \cdot 10^6$	$91 \cdot 10^6$	$101 \cdot 10^6$
Electrons & positrons ($E_{e^\pm} > 0.1$ MeV)	$1.3 \cdot 10^6$	$0.75 \cdot 10^6$	$0.86 \cdot 10^6$	$1.1 \cdot 10^6$	$0.92 \cdot 10^6$
Charged hadrons ($E_{h^\pm} > 0.1$ MeV)	$0.011 \cdot 10^6$	$0.032 \cdot 10^6$	$0.017 \cdot 10^6$	$0.020 \cdot 10^6$	$0.044 \cdot 10^6$
Muons ($E_{\mu^\pm} > 0.1$ MeV)	$0.0012 \cdot 10^6$	$0.0015 \cdot 10^6$	$0.0031 \cdot 10^6$	$0.0033 \cdot 10^6$	$0.0048 \cdot 10^6$

The straight sections of the collider complex have a unique potential to study high-energy neutrino scattering

- $10^5 / \text{m} / \text{bunch} \times 100 \text{ m} \times 10^5 \text{ kHz} \times 10^7 \text{ s/year} = 2 \times 10^{19} \text{ neutrinos year}$
- Neutrino interaction probability $4 \times 10^{-10} \times [E/\text{TeV}] \times [L/\text{m}] \times [\text{density}/\text{g cm}^{-3}]$
- At 1 km, the neutrino beam section will be $O(10 \text{ cm})$

Same as for forward tagger, we need to design / implement and evaluate the potential of such a detector

Towards 10 TeV

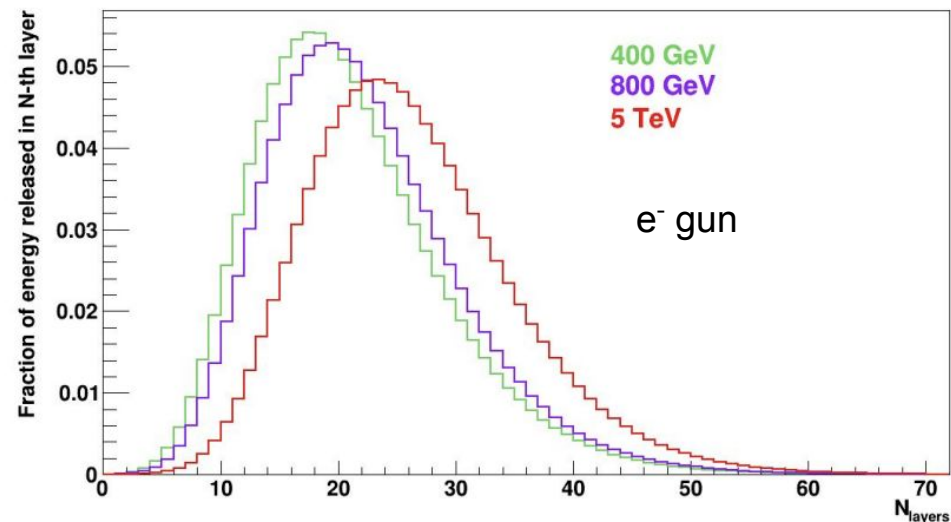
Towards a 10 TeV detector

The design of the 3 TeV CLIC detector is not suitable for 10 TeV

- Tracker layout and magnetic field strength might need an optimisation (beyond the MDI)
- The calorimeters can't fully contain the showers
- Not obvious that a high-precision muon system is needed (at least in barrel region)

Start with simplified studies based on particle guns shot on simplified geometries to define layout and technology.

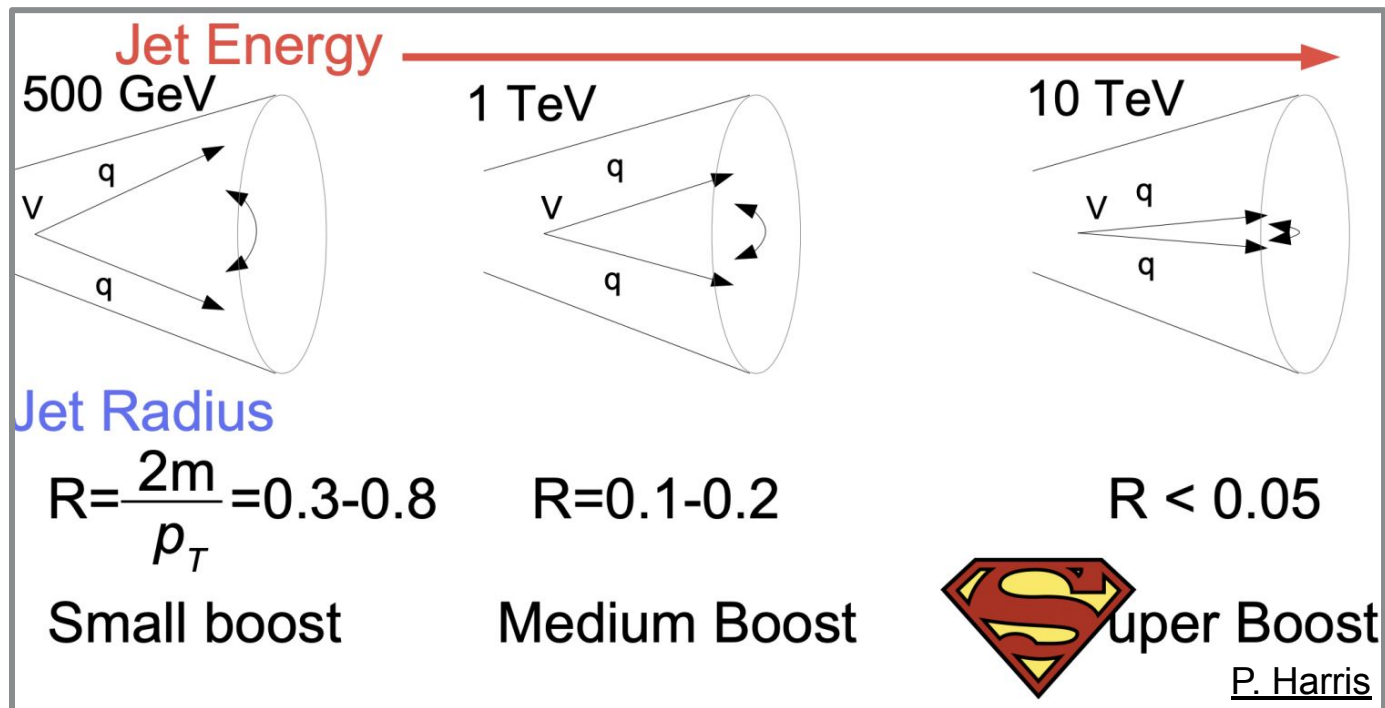
- Refine and integrate later



Towards 10 TeV reconstruction

The reconstruction algorithms that we designed (or simply inherited) at 3 TeV are not guaranteed to work at 10 TeV.

- Significantly different energy regime
- Higher detector granularity might require new approaches
- Different BIB and MDI



Come to our meetings!

Advertise your work

Get feedback

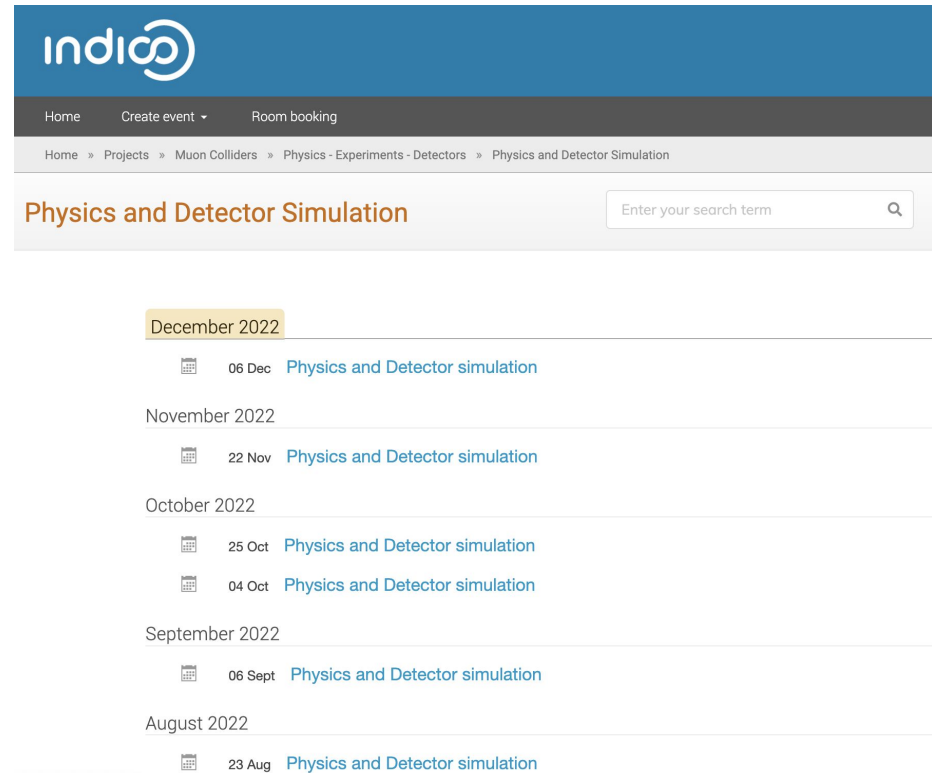
Keep the community informed

Find partners to turn your framework contribution into a public result

Tuesdays at 16:00 CERN

<https://indico.cern.ch/category/13145/>

- Alternating between general and technical meetings



The screenshot shows the Indico website interface. At the top is the Indico logo and a navigation bar with links: Home, Create event, and Room booking. Below the navigation bar is a breadcrumb trail: Home » Projects » Muon Colliders » Physics - Experiments - Detectors » Physics and Detector Simulation. The main heading is 'Physics and Detector Simulation' with a search bar to its right. The page displays a list of events categorized by month:

- December 2022**
 - 06 Dec [Physics and Detector simulation](#)
- November 2022**
 - 22 Nov [Physics and Detector simulation](#)
- October 2022**
 - 25 Oct [Physics and Detector simulation](#)
 - 04 Oct [Physics and Detector simulation](#)
- September 2022**
 - 06 Sept [Physics and Detector simulation](#)
- August 2022**
 - 23 Aug [Physics and Detector simulation](#)

Thank you!